Selection at the T2K Far Detector: Super-Kamiokande

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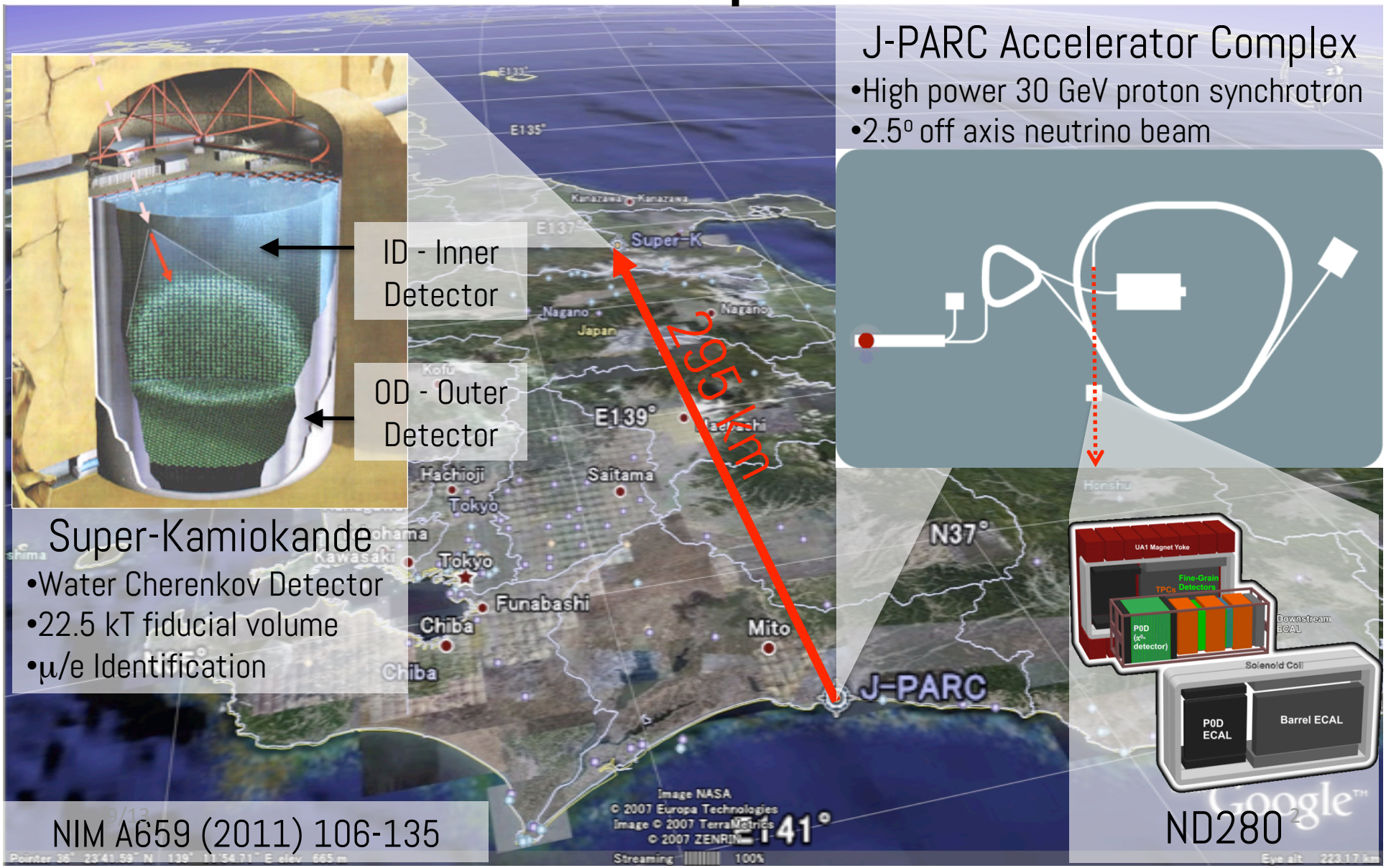
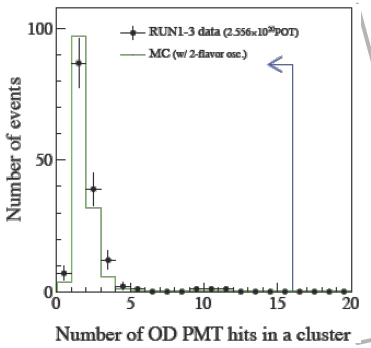
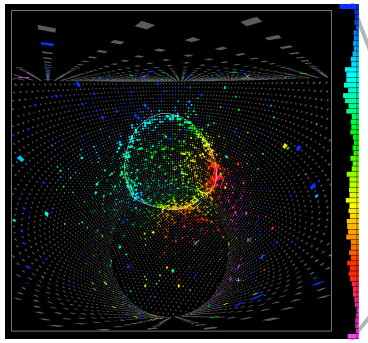
The T2K Experiment

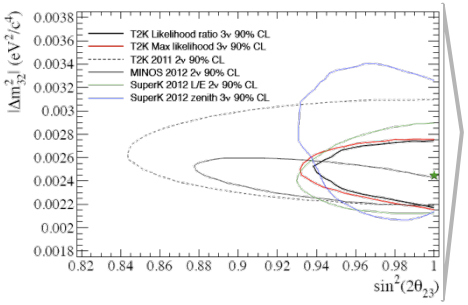


NIM A659 (2011) 106-135

Super-K Data Flow







Event Selection Beam Timing

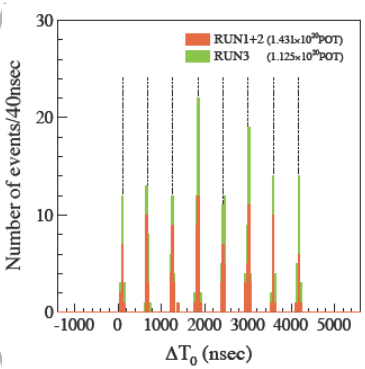
Cuts to remove background

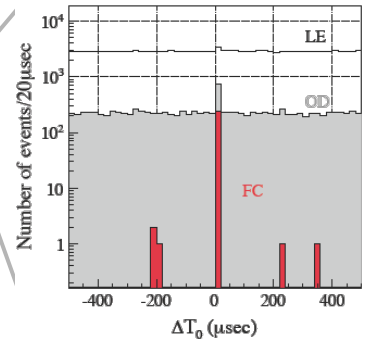
Event Classification

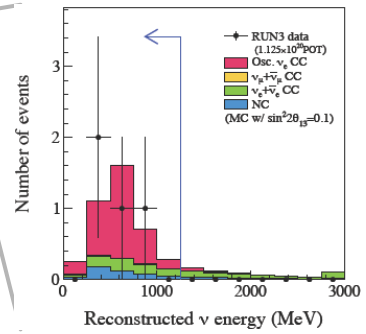
Event reconstruction

Cuts to select ν_e and ν_μ for analysis

Oscillation analysis
(not discussed in this talk)



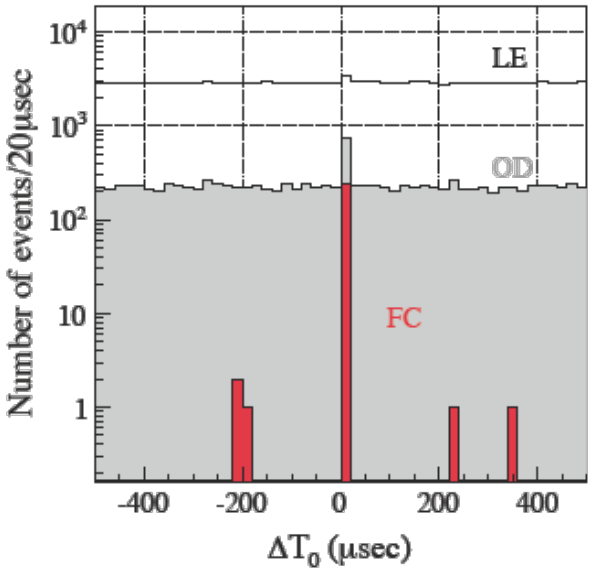




arXiv hep-ex/1304.0841

Timing and Event Classification

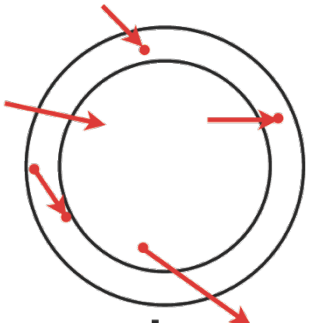
Timing



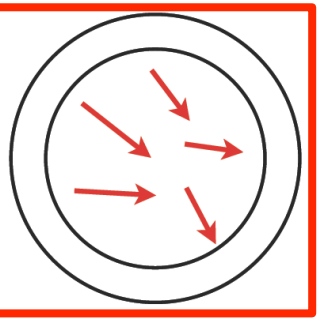
- GPS time stamps give beam timing from J-PARC
- Events in -2μs – 10μs window of beam timing selected

Event Classification

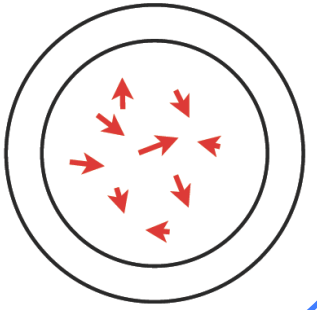
- Outer Detector (OD)
  - >16 PMT hits in OD



- Fully Contained (FC)
  - <16 PMT hits in OD
  - >30 MeV Visible Energy in inner detector (ID)



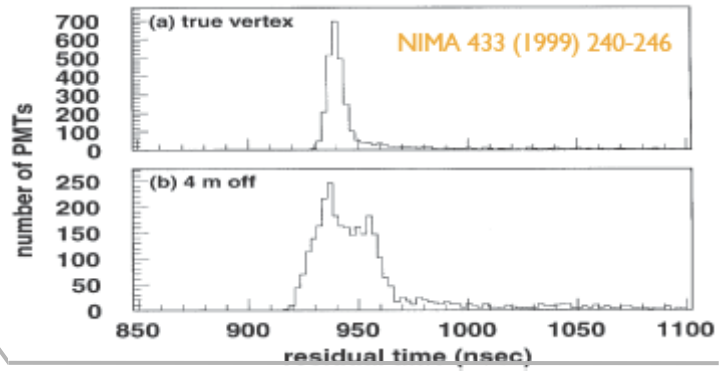
- Low Energy (LE)
  - <16 PMT hits in OD
  - <30 MeV Visible Energy



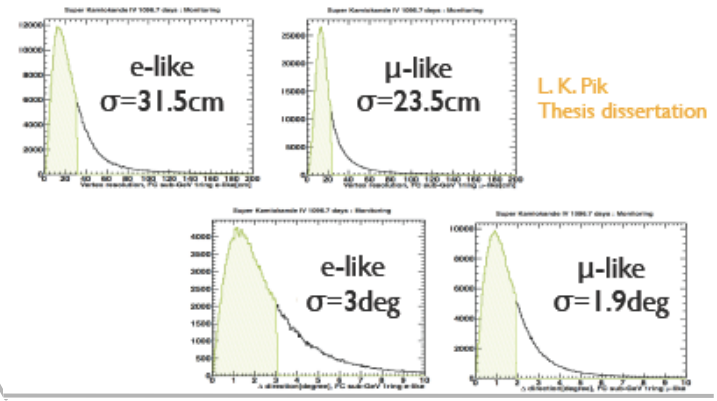
Event Reconstruction

- TDC-fit
- Ring Counting
- Particle Identification
- MS-fit
- Momentum reconstruction
- Decay electron search
- π^0 fitter

Vertex determination from TOF



Precise vertex and direction fitter



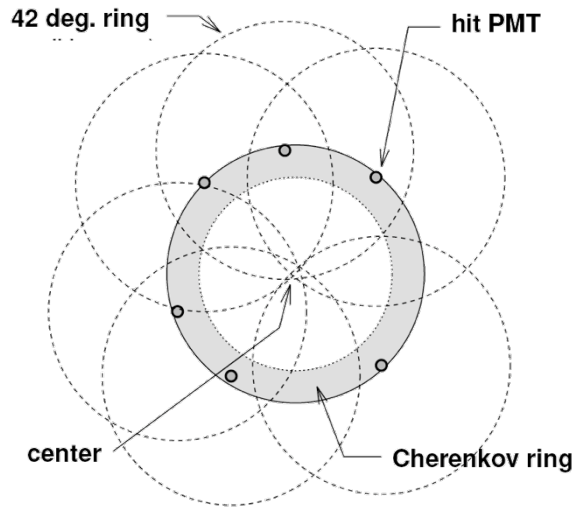
Search: 50 μs window with 50 ns sliding window

Ring Counting and PID

Ring Counting

Hough Transform technique:

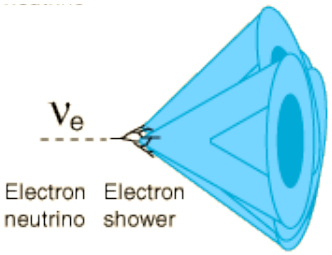
- 42^0 ring drawn from each PMT to fill Hough space
- Peaks correspond to rings
- Repeated up to 5 times, removing contribution from previous rings

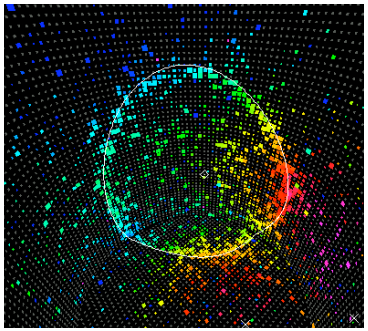


Particle Identification

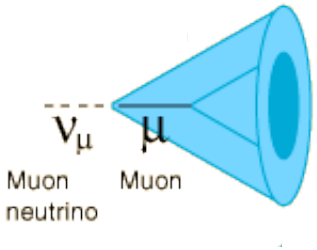
PID assigned based on Likelihood, tested with scaled detector in test-beam

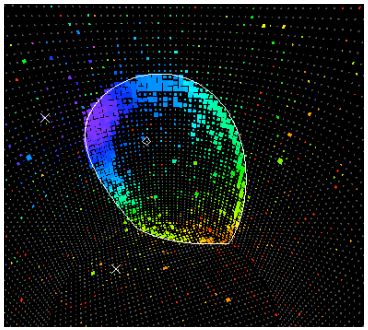
Electron-like fuzzy rings





Muon-like sharp rings

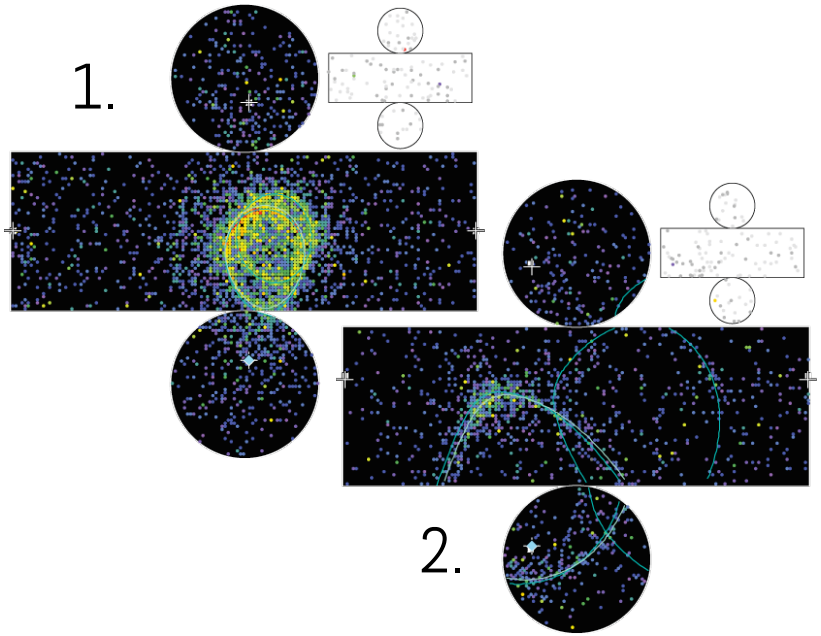


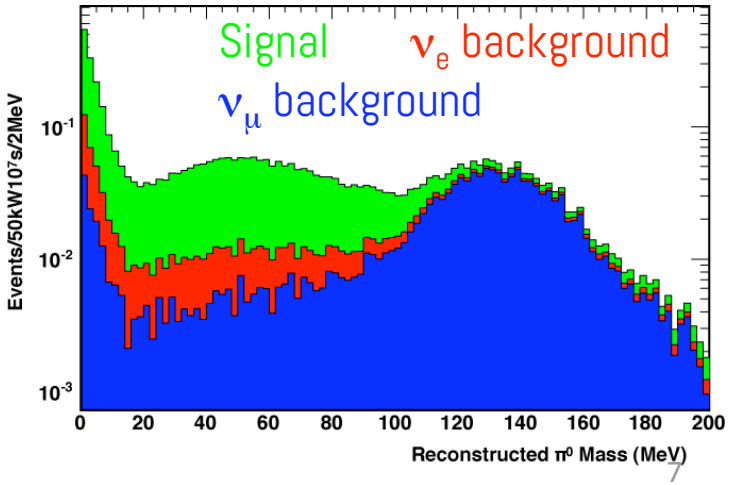


π^0 Fitter

- Neutral Current π^0 events main background to ν_e appearance analysis because of:
  1. Overlapping gamma shower rings
  2. Asymmetric π^0 decay with 2nd ring invisible

- Force a search for second ring and reconstruct an invariant mass from the two rings





Cuts for ν_μ Analysis Sample

Fiducial volume (FV)

Fully contained (FC)

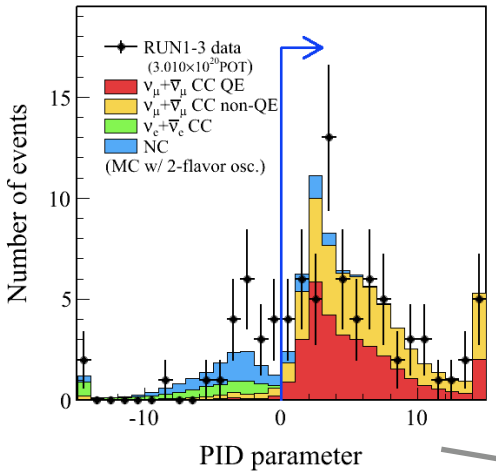
Single ring (1R)

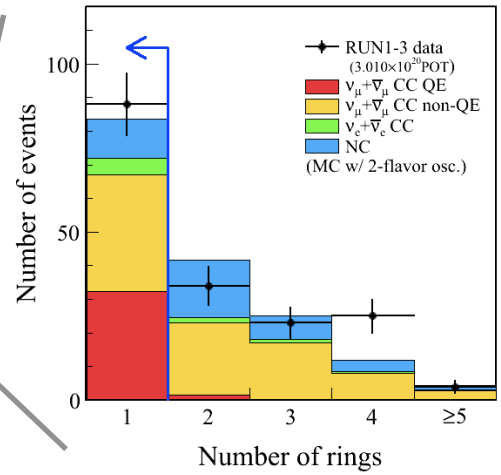
μ-like PID

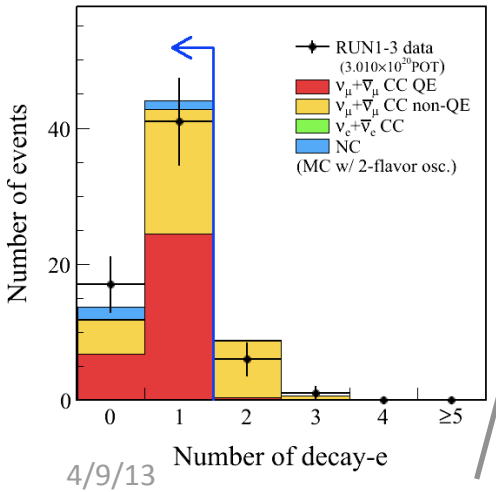
p_μ > 200 MeV/c

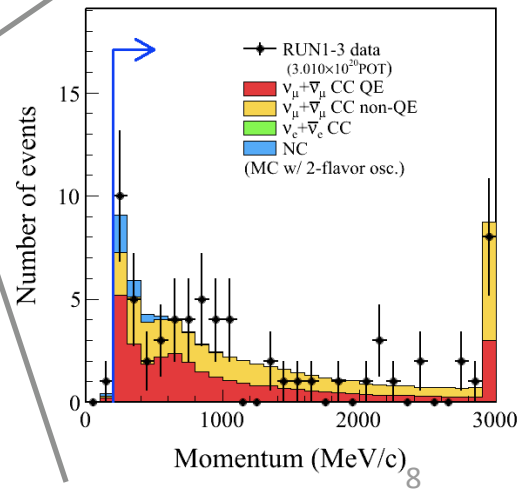
N°. decay electrons <=1

ν_μ oscillation sample









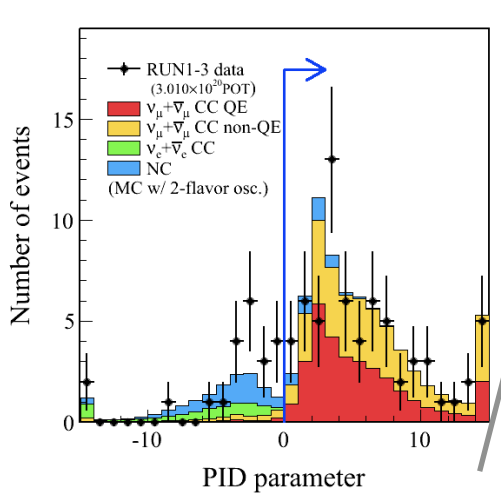
Cuts for ν_μ Analysis Sample

RUN 1+2+3 3.010 x10^{20} POT	Data	MC Expectations w/ Oscillation				
		MC Total	ν_μ+anti-ν_μ CCQE	ν_μ+anti-ν_μ CC non-QE	ν_e+anti-ν_e CC	NC
True FV	-	296.67	45.22	110.25	8.31	132.89
FV + FC	174	166.61	34.37	83.83	7.93	40.48
One-ring	88	83.56	32.47	34.52	5.03	11.55
μ-like	66	67.74	31.83	32.42	0.04	3.45
p_μ > 200 MeV/c	65	67.33	31.60	32.35	0.04	3.34
$N_{dcy\text{-}e}$ <=1	58	57.78	31.25	23.29	0.03	3.21
Efficiency [%]	-	19.5	69.1	21.1	0.4	2.4

arXiv hep-ex/1201.1386

MC assuming 2-ν oscillation w/ $\sin^2 2\theta_{23} = 1.0$, $\Delta m^2_{23} = 2.4 \times 10^{-3}$ eV2

Cuts for ν_e Analysis Sample



FV + FC + 1R

e-like PID

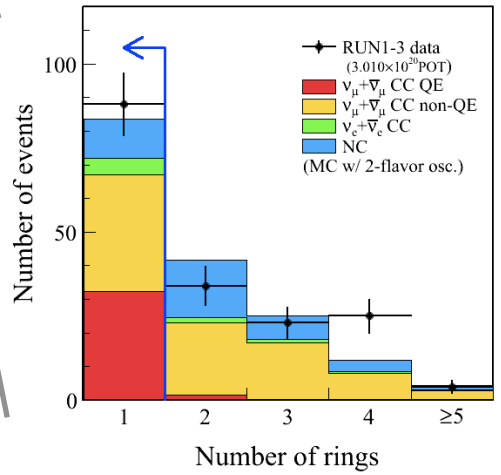
Visible energy > 100 MeV

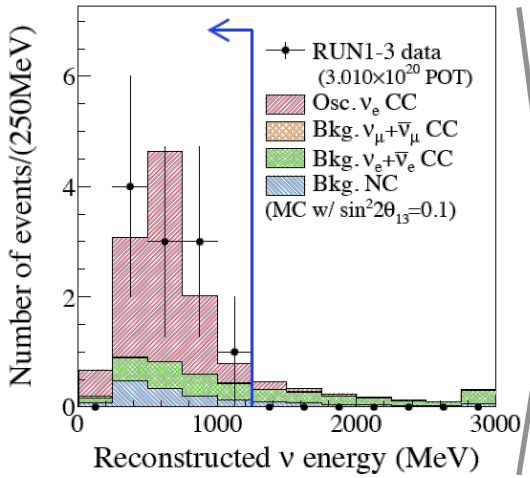
Zero decay electrons

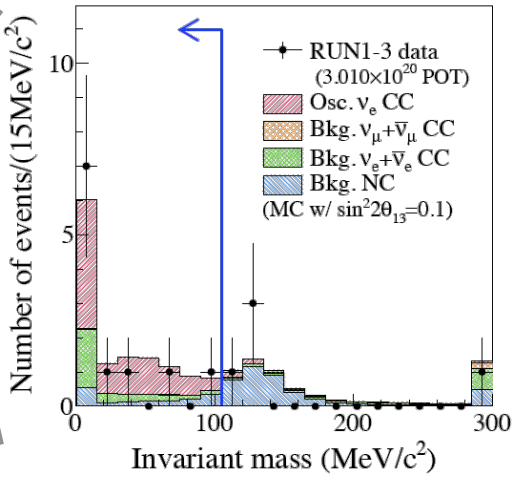
π^0 inv. mass < 105 MeV/c^2

Recon. E_ν < 1250 MeV

ν_e oscillation sample







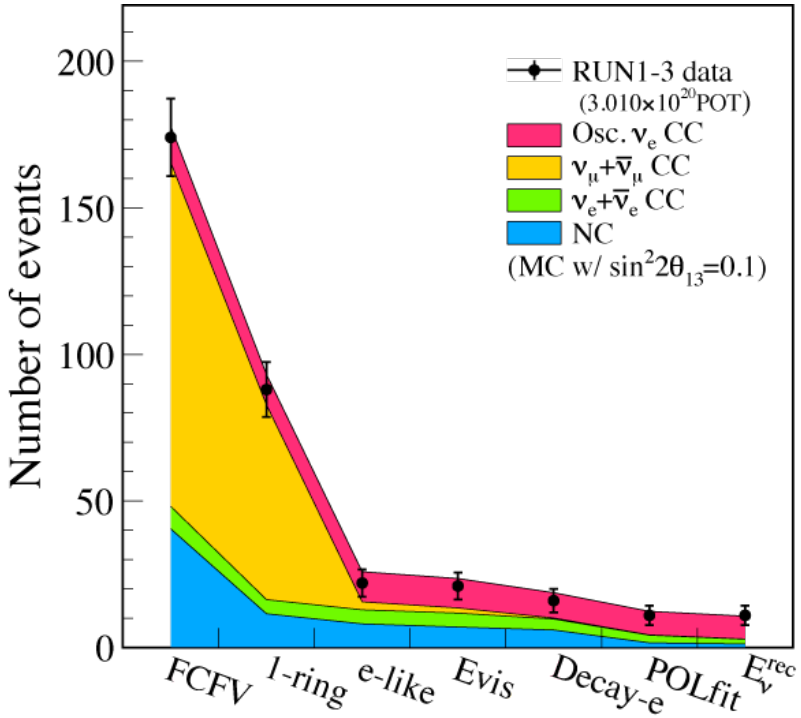
Cuts for ν_e Analysis Sample

RUN 1+2+3 3.010 x10^{20} POT	Data	MC Expectations w/ Oscillation				
		MC Total	ν_μ+anti-ν_μ CC	ν_e+anti-ν_e CC	NC	$\nu_\mu \rightarrow \nu_e$ CC
True FV	-	311.4	158.3	8.3	131.6	13.2
FV + FC	174	180.5	119.6	8.0	40.2	12.7
One-ring	88	95.7	68.4	5.1	11.4	10.8
e-like	22	26.4	2.7	5.0	8.0	10.7
Evis > 100 MeV	21	24.1	1.8	5.0	6.9	10.4
$N_{dcy\text{-}e}$ = 0	16	19.3	0.3	4.0	5.9	9.1
π^0 mass < 105 MeV/c^2	11	13.0	0.09	2.8	1.6	8.5
E_ν < 1250 MeV	11	11.2	0.06	1.7	1.2	8.2
Efficiency [%]	-	3.6	0.04	20.5	0.9	62.12

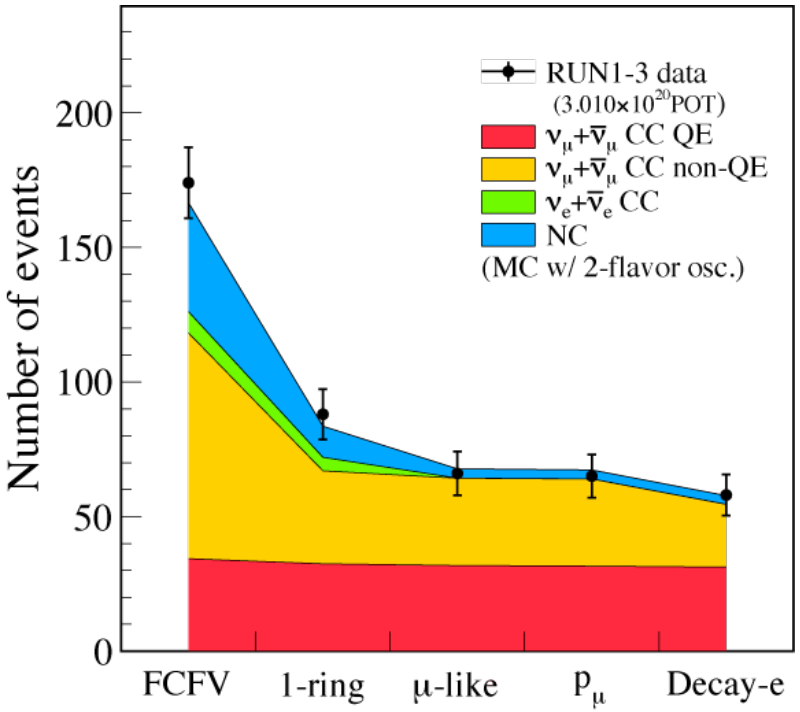
arXiv hep-ex/1304.0841

MC assuming 3-ν oscillation w/ $\sin^2 2\theta_{13} = 0.1$, $\delta_{CP} = 0$

Summary of Cuts for Analysis Samples



ν_e appearance

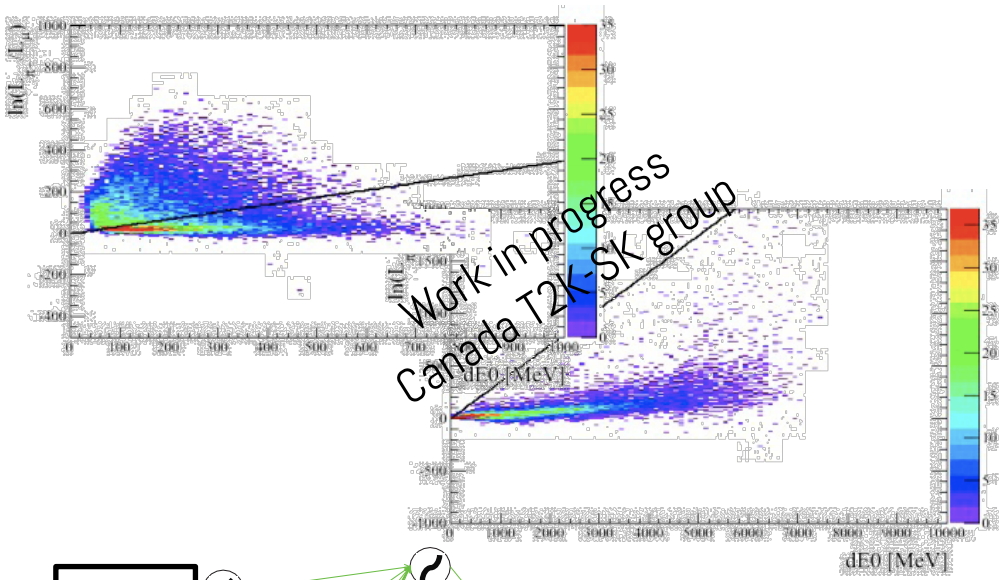


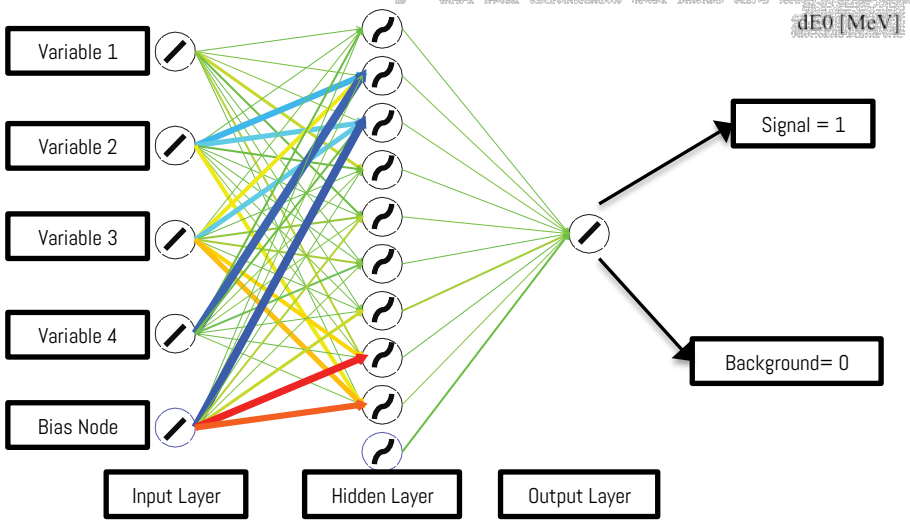
ν_μ disappearance

Oscillation Analysis

Future

- New event reconstruction techniques fiTQun
  - Improved π^0/e discrimination
  - Possible μ/π separation
- Multivariate selection methods
  - Select different kinematic regions
  - Complementary and improved selection of ν_e and ν_μ events.





Multilayer Perceptron (MLP)

FV + FC + 1R

↓

Visible energy > 100 MeV

↓

Zero decay electrons

↓

MLP Cut

↓

Recon. E_ν

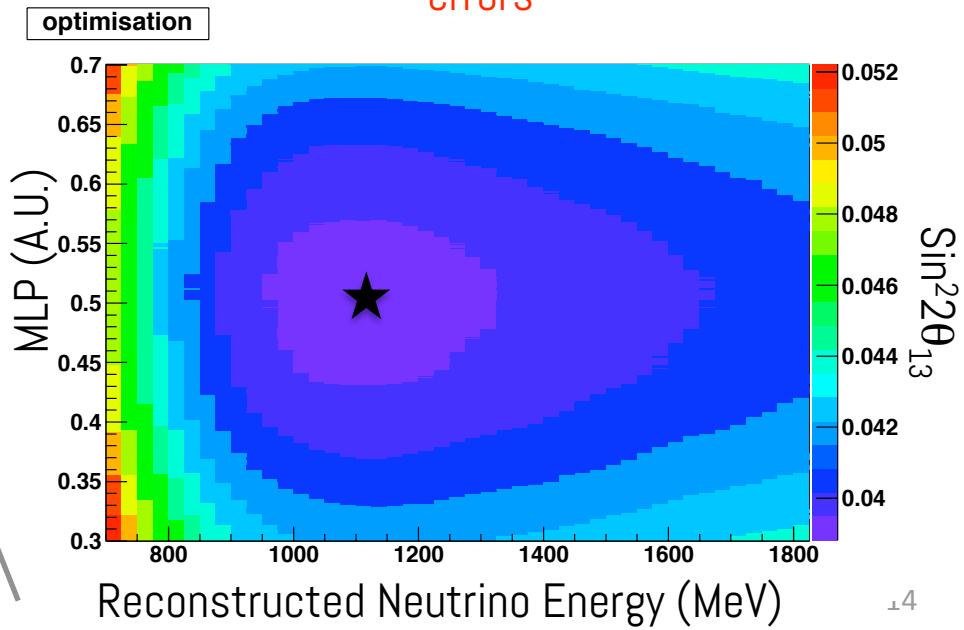
↓

ν_e oscillation sample

Work in progress @QMUL

Training	MLP	Current Analysis
Cut Value	0.51 (A.U.)	105 (MeV)
E_ν^{Rec} (MeV)	1125	1250
Sens. 90% C.L. to $Sin^2 2\theta_{13}$	0.038	0.056

Equal 10% BG and 10% signal systematic errors



Conclusion

- Super Kamiokande is working perfectly as the T2K far detector
- 11 candidate ν_e and 58 ν_μ events recorded so far with ~4% of total POT
- New methods will improve reconstruction and selection.